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Full-scale model tests of a steel catenary riser

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Abstract

Steel catenary risers (SCRs) are an enabling technology for deepwater oil and gas production. Tools to analyse and design SCRs are available which show that the point where the riser first touches the soil, termed the touchdown point (TDP) is critical. However our understanding of fluid/riser/soil interaction is limited, hence the oil and gas industry has concerns regarding the levels of conservatism in SCR design, and margins of safety. The purpose of this study is to examine the interaction between a pipe (representing a section of the SCR), a clay seabed, and the surrounding seawater.

This paper documents some of the results and observations from the full scale harbour test riser experiments which examined the 3D effect of fluid/riser/soil interaction around the TDP. The riser, a 110m (360-ft) long 0.1683m (6-5/8 inch) diameter pipe, was draped from an actuator on the harbour wall to an anchor point on the seabed. The top end of the pipe string was actuated using a programmable logic controller (PLC) to simulate the wave and vessel drift motions of a spar platform in 1000m (3,300-ft) water depth, both in-line and transverse to the SCR plane. The pipe was fully instrumented to provide tensions and bending moments along its length.

Observations from the harbour tests show that a trench forms around the TDP. Evidence collected shows that the trench created was tear-drop shaped, with a maximum width of 2.5 riser diameters and a maximum depth of 1.2 diameters. The trench was thought to be created from a combination of the applied vessel motions and fluid flow across the riser and the seabed, however the exact trenching mechanisms are unknown.

The work was conducted as part of the successful STRIDE JIP (Steel Risers in Deepwater Environments Joint Industry Project).

1 Introduction

1.1 Steel catenary risers

A SCR is a long steel pipe that hangs freely between the seabed and a floating production system. The top of a SCR is connected to the floating production system, where it hangs at a prescribed top angle. The riser is free-hanging and gently curves down to the seabed to the TDP. At the TDP the SCR buries itself in a trench and then gradually rises to the surface where it rests, and is effectively a static pipeline. SCRs may be described as consisting of three sections as shown in Figure 1, below:

- Catenary zone, where the riser hangs in a catenary section
- Buried zone, where the riser is within a trench
- Surface zone, where the riser rests on the seabed

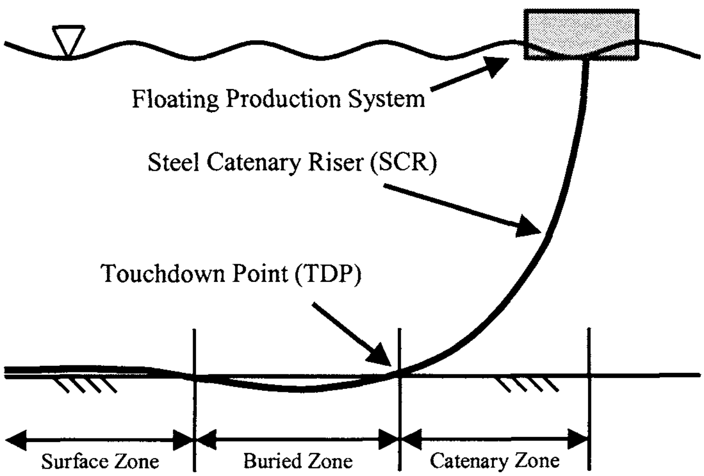

Figure 1: General Catenary Arrangement

Predicting the shape and general forces on a SCR is a relatively simple process, the most basic of which is to solve standard catenary equations. More detailed analysis of risers can be conducted using non-linear finite element analysis programs. Most specialist state-of-the-art riser analysis codes use either rigid or linear elastic contact surfaces to simulate the seabed, which model vertical soil resistance to pipe penetration, horizontal friction resistance and axial friction resistance. A rigid surface generally gives a conservative result since it is unyielding, while the linear elastic surface is a better approximation of a seabed.

1.2 Vessel motions

The vessel from which the SCR hangs is generally a floating production vessel, and as such is subject to wave, current and wind loading. During normal operating conditions the SCR connects to the vessel via either a flex joint or a taper stress joint. These transfer the dynamic motions of the vessel directly to the top of the SCR, which causes the TDP to move along the riser. It has been found that of all the vessel motions, heave causes the greatest stress fluctuations at the TDP [1]. Analysis has shown that a dynamic heave motion of ±1m amplitude can cause the TDP on a SCR in 1000m water depth to move horizontally by 10m. The main forms of loading on vessels are described below:

- First order motions – wave frequency motions caused by wave action on the vessel.
- Second order motions – low frequency motions caused by wind gusts, often referred to as slow drift motions.
- Static offset – displacement resulting from mean environmental loads such as currents, waves and winds, or system failures, such as failed mooring lines.

In addition to the vessel loads the current acts directly on the SCR. This causes the riser to flex in the direction of the current, and can invoke high frequency vortex induced vibration (VIV) motions in the riser.

1.3 Touchdown point

Deepwater oil and gas fields usually have seabeds of soft clay. ROV surveys of installed SCRs have shown deep trenches cut into the seabed beyond the TDP. The mechanisms that create these trenches are unknown, however they are thought to be produced by the dynamic motions of the riser combined with the scouring and sediment transportation effects of the seabed currents.

Storm and current action on a deepwater production vessel can pull the riser upwards from its trench, or laterally against the trench wall. This interaction could cause an increase in the local riser stresses (due to tighter riser curvatures and higher tensions) than those predicted ignoring the seabed trench.

1.4 Harbour tests

As part of the STRIDE III JIP, 2H Offshore Engineering Ltd conducted a full-scale test programme to investigate the effects of fluid/riser/soil interaction on catenary riser response and wall stresses, Figure 2 at the TDP. The objective was to assess the importance of fluid/riser/soil interaction, and to produce finite element (FE) analysis techniques to predict the measured response.

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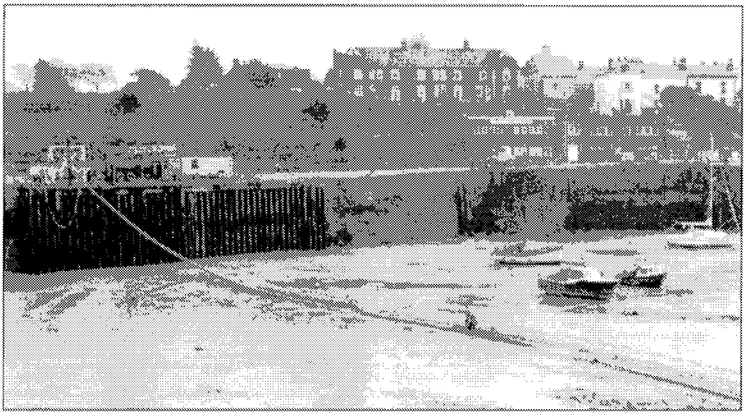

Figure 2: Full scale harbour test riser

2 Harbour test riser

The test programme was conducted over 3 months at a harbour location in the west of England. A 110m (360-ft) long 0.1683m (6-5/8 in) diameter, 6.9mm wall thickness welded steel (APL 5L Grade B) riser was suspended from an actuator on the harbour wall and run out across the seabed to a set of mud anchors, Figure 3. The seabed over this area was flat and undisturbed, and careful probe tests were done to check that there were no hidden obstacles below the mudline.

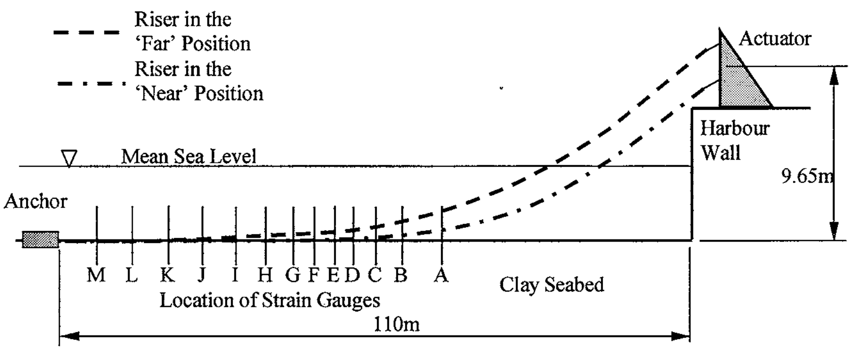

Figure 3: Harbour test set up and the locations of strain gauges A to M

The harbour tests riser was completely instrumented with 13 sets of strain gauges measuring vertical and horizontal bending strain which spanned the TDP area, Figure 3, and load cells measuring the tensions and shear forces at the

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actuator and the tension at the anchor. In addition triaxial accelerometers were placed on the actuator and at strain gauge position A. All instrumentation was hard wired back to a real time, 40hz multi-channel logging station.

2.1 Marine parameters

The mean sea level was 3.5m above the anchor. The current velocity due to the tides in the test area as the harbour filled or emptied was low. Tests were conducted at both high and low tides.

2.2 Geotechnical parameters

The Watchet Harbour seabed is known to have properties similar to a deepwater Gulf of Mexico seabed. This is made up of soft clay, with an undrained shear strength of 3 to 5 kPa, a sensitivity of 3, a plasticity index of 39%, and a naturally consolidated shear strength gradient below the mudline. Further geotechnical properties are given by Bridge & Willis [2].

2.3 Test program

The harbour tests were conducted over a 6 week period on numerous test corridors including an open trench, an artificially deepened trench, a backfilled trench and on a rigid seabed. For each test corridor a series of tests was conducted to examine the effects of slow drift (pull up and lay down tests) and dynamic motions (day-to-day and second order motions), Table 1.

Table 1: Actuation definitions and parameters with equivalent SCR motions

Actuation Reference	Offshore Equivalent Motion	Travel at Actuator
Dynamic @ near / nominal / far	Heaving storm wave about either the 0.5% WD near, nominal, 1.1% far vessel position	Vertical sine wave, +/- 0.4m, 25 second period about the -0.4m datum, 0m datum, +1.0m datum
Pull-up	Spar failed mooring drift speed, near 0.8% to far 1.4% WD	-0.8m to +1.4m @ 0.1m/s and 0.01m/s
Lay-down	Spar failed mooring drift speed, far 1.4% to near 0.8% WD	+1.4m to –0.8m @ 0.1m/s and 0.01m/s

3 Typical results from the harbour test riser

The results from the harbour test riser are presented as bending moment traces versus actuator position at strain gauge locations. Comparisons are made between the bending moment data from a strain gauge during pull up and lay down tests. A negative bending moment corresponds to a sagging bend in the riser.

An example of a typical bending moment trace with actuator position is given in Figure 4. It shows that when the actuator is at -0.8m, at the bottom of the vertical stroke, the bending moment is around 0.5kNm. As the actuator moves upwards the bending moment is constant until the actuator reaches -0.6m, after which the bending moment reduces to a peak of –6kNm at an actuator position of 0.8m. The bending moment then reduces to –5.5kNm at an actuator position of 1.4m.

Initially the pipe location is on the seabed, in the surface zone. Then as the actuator moves the top of the pipe upwards the pipe location moves into and through the buried zone, until at the end of the actuation the pipe location is free hanging in the catenary zone. During this actuation the TDP is observed to move 25m towards the anchor. Further results from the harbour tests have been presented by Bridge & Willis [2].

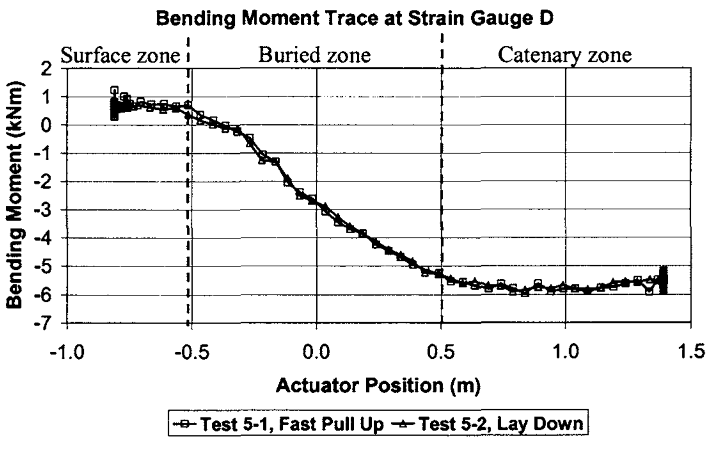

Figure 4: Comparison of pull up and lay down tests on a rigid seabed

4 Observations of riser trenches

When the harbour test riser was initially placed on the seabed the soil deformed to create a close fitting trench around the pipeline. This close fitting trench was observed at low tide after the riser had been floated into place.

During the testing the trench was observed to deepen and widen around the TDP. A photograph of the trench formed is given in Figure 5. This shows the section of the harbour tests riser as it passes from the catenary zone, through the TDP into the buried zone and then into the surface zone where the pipe is connected to the anchor. The trench formed starts where the riser first touches

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the soil when the actuator is at its lowest position (which it was between most tests). The trench extends towards the anchor and the width increases from 1 diameter to a maximum of 2.5 diameters over a distance of 20m. The trench then reduces in width to 1 diameter over the next 40m at which point it is considered to be a static pipeline in the surface zone.

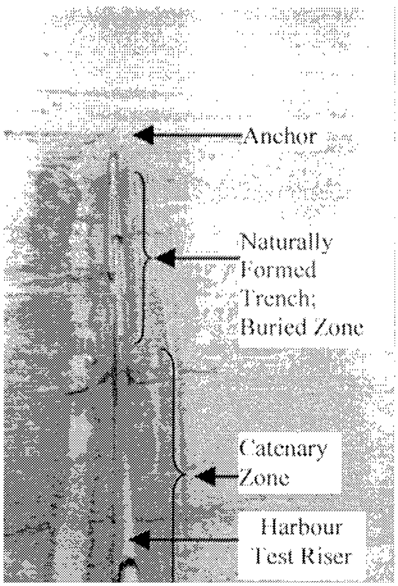

Figure 5: The harbour test riser in a naturally occurring seabed trench at low tide

Two close ups of the trench are shown in Figure 6. Both photographs are taken from the widest part of the trench, Photograph A faces the anchor and the surface zone while Picture B faces the actuator and the catenary zone. The photographs show that there is no build up of soil around the top of the trench, which may be expected if the riser had been pushed into the trench walls by the tidal currents. It can also be seen that the tops of the trench wall are curved which could have been warn away by the tidal currents.

Measurements taken during the testing program, Figures 7 and 8, show the trench to be tear-drop shaped and that the maximum depth and width increases over the 6 week testing period from 0.5 diameters to 1.2 diameters and from 1 diameter to 2.5 diameters respectively.

The mechanisms that created the trench are unknown, however there are many possibilities including:

- The dynamic motions applied by the actuator, representing the vessel motions, may have dug the trench. In addition any vertical motion at the

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TDP would cause the water beneath the riser to be pumped out of the trench, carrying sediment with it.

- The flow of the tides may have scoured and washed away the sediment around the riser.
- The flow of the seawater across the riser can cause VIV (which was observed when the tide came in or went out). This high frequency motion could act like a saw, slowly cutting into the seabed.
- When the harbour test riser is submerged the buoyancy force causes the riser to lift away from the seabed. Any lose sediment in the trench or attached to the riser would be washed away.

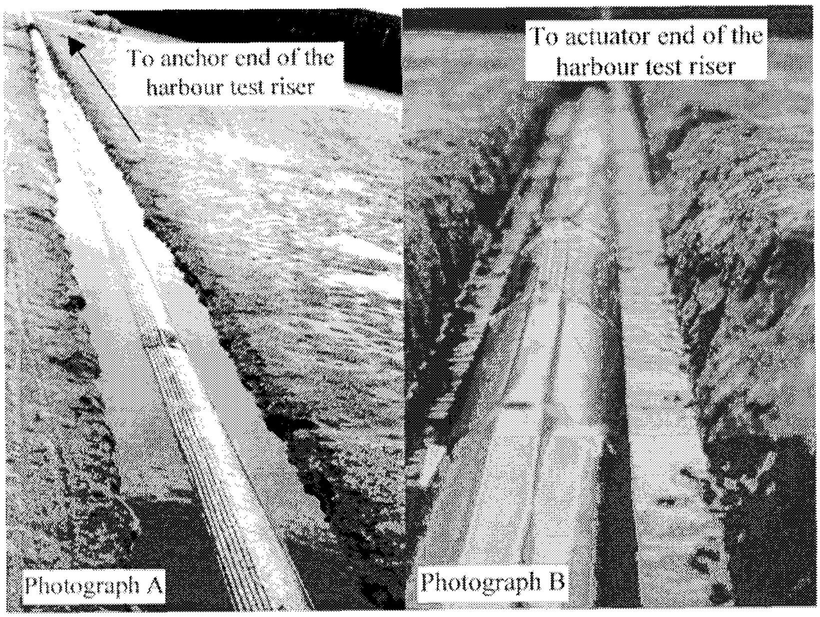

Figure 6: Close up photographs of the trench at low tide

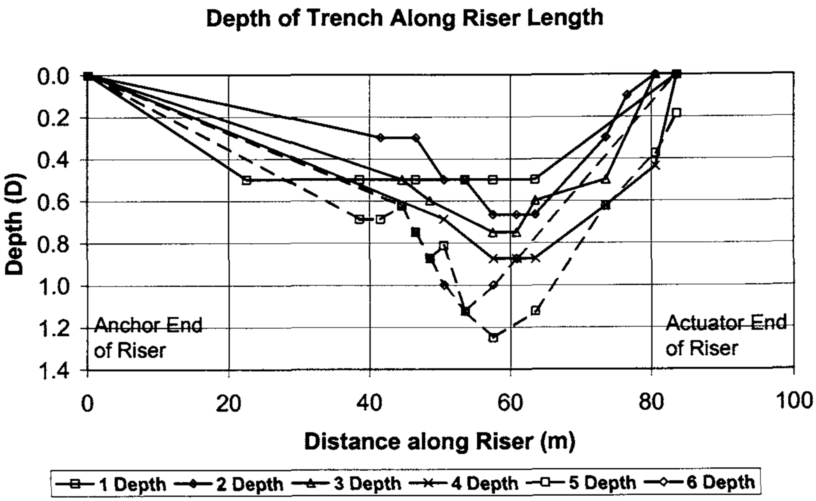

Figure 7: Measurements of trench depth

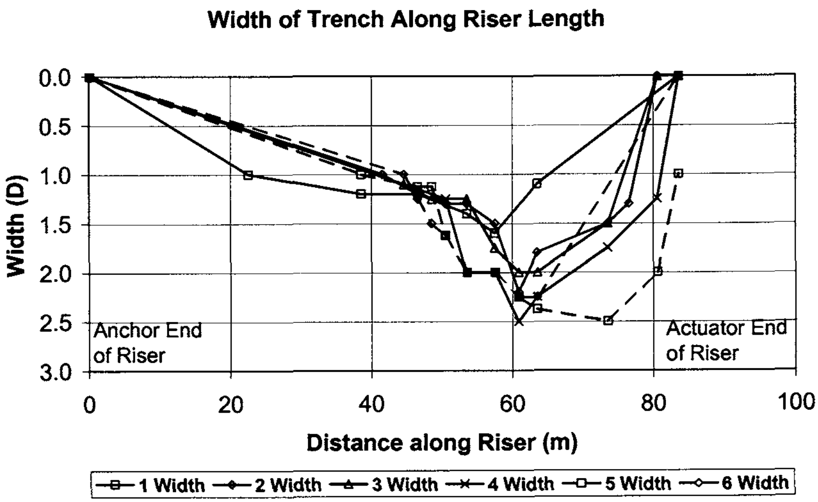

Figure 8: Measurements of trench width

5 Conclusions

The full-scale tests provide a valuable basis for evaluation of SCR fluid/riser/soil interaction and validation of analytical models. A comparison of the pull up and lay down tests on the rigid seabed shows that the bending moment data is consistent between similar tests.

Evidence collected from the harbour tests show that over a period of 6 weeks a trench was created near the TDP which was tear-drop shaped, with a maximum width of 2.5 diameters and a maximum depth of 1.2 diameters. The trench is thought to be created from a combination of the applied motions and fluid flow across the riser and the seabed, however the exact trenching mechanisms are unknown. Further work is required to determine the primary trenching mechanisms so that accurate predictions can be made to reduce the conservatism in SCR design.

Acknowledgements

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